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MINER ACT TECHNOLOGY: PAST, PRESENT, AND FUTURE

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The Mine Improvement and New Emergency Response Act of 2006 (MINER Act Public Law 109-236) was passed by Congress in response to three major underground coal mine accidents in the United States that claimed the lives of 19 miners. The Act resulted in substantial changes in the underground coal industry relative to the use of technology for mine escape, rescue, disaster response and other areas where the lack of these technologies contributed to the fatalities caused by these tragedies. This year marks the 10th anniversary of the MINER Act, which makes it an opportune time to reflect on the events that led to its passage, the changes that have been made since then, and the work that remains to be done.

As discussed below, the last decade has demonstrated tremendous cooperative efforts among mining operators, technology innovators, labor, The National Institute for Occupational Safety and Health (NIOSH), the U.S. Mine Safety and Health Administration (MSHA) and state regulators, resulting in substantial improvement of the technologies used for escape and rescue and noteworthy progress toward meeting many of the goals of the MINER Act. While the MINER Act and this article pertain primarily to coal mining, many of the technologies are equally applicable to any underground mining and have already found some acceptance outside of coal.

TECHNOLOGY GAPS TARGETED BY THE MINER ACT

The MINER Act addressed several technology challenges:

- Problems with donning and switching between self-contained self-rescuers (SCSRs).
- Poor visibility in smoke.
- No wayfinding assistance for escape from the mine.
- Limited breathable air supply.
- Inability to locate trapped miners.
- Inability to communicate with trapped miners.
- Failure of mine seals.

The MINER Act had several provisions that prescribed specific safety technologies intended to address these issues. Many of these were directed at post-accident technology requirements — an area in which Congress mandated additional technology investment. Specifically, the Act required mine operators to submit emergency response plans (ERPs) that contained provisions for implementing new or improved post-accident communications, tracking, lifelines, refuge alternatives and breathable air supplies along with training for emergency procedures and local coordination of emergency response. Most of the requirements were to be carried out within three years of the ratification of the MINER Act.

In addition to these requirements for mine operators, the Act clarified and expanded NIOSH's role and authority in enhancing the development of new mine safety technologies and expediting their commercial availability. The MINER Act also required NIOSH to develop research on refuge chambers, mine seals and the use of belt air and fire-retardant belts. Mine seals had to be upgraded and MSHA turned to NIOSH for applied research to establish the new explosion-resistance requirements.

Progress toward closing the gaps.

The years following the MINER Act saw an impressive amount of progress toward closing the technology gaps due to an unprecedented availability of funds and the cooperation of researchers, mine operators, labor and regulators to work toward a common goal.

The following is a summary of highlights describing NIOSH's approach to closing the technology gaps and the current state of the industry as related to the specific technology objectives of the MINER Act.

POST-ACCIDENT COMMUNICATIONS

The MINER Act required that a mine's ERP shall initially "provide for a redundant means of communication with the surface for persons underground, such as secondary telephone or equivalent two-way communication." Additionally, a plan was required to "provide for post-accident communication between underground and surface personnel via a wireless two-way medium." MSHA defined "wireless" to mean "that no wired component of the system exists underground where it may be damaged by fire or explosion" (MSHA 2006).

NIOSH's approach to the problem

NIOSH arrived at an internal strategy or "roadmap" for the development of communications systems. The first part of the strategy was to develop systems within the three-year time frame of the MINER Act, using well-known approaches and providing enough wireless communications bandwidth to support day-to-day mine operations as well as emergency communications. These systems are referred to as *primary* communications systems, and included the development of the wireless mesh system (node-based) and enhanced redundancy leaky feeder systems.

Even with hardening and redundancy, primary communications systems require vulnerable infrastructure that can be damaged in a mine disaster. Therefore, the view was that post-disaster communications systems would need alternate communications pathways to the surface to improve network reliability and survivability, and to be more closely aligned to the MSHA definition of "wireless." The best options for these alternate communications paths were found to be through-the-earth (TTE) and medium frequency systems, neither of which has sufficient bandwidth to support day-to-day operations, but require limited or no mine infrastructure to operate. These systems are referred to as *secondary* systems (NIOSH 2007a).

Current state of the industry

Based on a recent NIOSH study, mining operators have installed primary communications systems in 100 percent of the coal mines in the United States, with 56 percent being node-based and 44 percent being leaky feeder (Damiano et al. 2014). This widespread adoption of primary systems was greatly aided by the fact that there was a general recognition that these systems are usable for day-to-day operations and would contribute to productivity gains as well as improved safety. The medium frequency and TTE secondary systems did not become available until after the mandated implementation dates in the Act, and neither has as of yet found ready acceptability within the industry.

POST-ACCIDENT TRACKING

The MINER Act required that a mine's ERP "provide for an electronic tracking system permitting surface personnel to determine the location of any persons trapped underground." It also required the plan to "provide for above ground personnel to determine the current, or immediately pre-accident, location of all underground personnel," and that any system be "functional, reliable, and calculated to remain serviceable in a post-accident setting."

NIOSH's approach to the problem

NIOSH researchers determined that there were several ways that electronic tracking could be accomplished in underground mines (NIOSH 2007a). Two methods were viewed to be implementable within the MINER Act time frame. The first was a zone-based approach using a series of readers in the mine, which would read an radio frequency identification (RFID) tag worn by the miner as he or she passed by the reader. The miner's location is inferred to be somewhere within a zone, defined by the reader spacing and location — hence the term "zone-based" tracking. For this technology, NIOSH determined that private funding was already sufficient to ensure that these systems would be available. The second method was to use the received signal strength (RSSI) from multiple antennas in the mine to continually triangulate the miner's position. While this approach offered several potential advantages, there were considerable technical questions about how well it would work in mines, which led to NIOSH funding a large-scale evaluation project of this technology as an integral part of a wireless mesh communications system.

Both of these options share the same vulnerability as primary communications systems. A third technology was considered in which the miner's location is estimated from the motion of the miner as measured by an inertial measurement unit (IMU) tag worn by the miner. This approach would theoretically provide a much more accurate and robust determination of the location, but *only* if the system could be made to work in the underground environment. Underground implementation over typical mine-size areas was problematic, so developing such a system within the MINER Act time frame was not feasible. With ongoing significant investment by the military and private sector for determining position in a "GPS-denied" environment, NIOSH continues to follow these developments in the anticipation that such a solution can ultimately be provided to underground mining through an integration of technologies.

Current state of the industry

All underground coal mines now have electronic tracking systems that are zone-based or RSSI-based (Damiano et al. 2014). The basis for the determination of an acceptable level of survivability and post-accident performance of a tracking system, including the pre-requisite communications link to the surface, is a difficult one and leads to different possible and subjective interpretations, particularly in the working section (Virginia Tech 2014).

POST-ACCIDENT LIFELINES

The MINER Act required that a mine's ERP "shall provide for the use of flame-resistant directional lifelines or equivalent systems in escapeways to enable evacuation." Further, these lifelines had to be installed upon replacement of existing lifelines or within three years — whichever was sooner.

NIOSH's approach to the problem

The purpose of the lifelines is to indicate the direction of escape to the miner even in zero visibility through tactile indicators. The shape of these indicators to determine direction, refuge chamber locations, caches of breathable air, etc., as well as the types of material used, were a direct result of research by NIOSH and its predecessor, the U.S. Bureau of Mines (USBM) (NIOSH 2005).

Current state of the industry

The mining industry has installed directional lifelines in all active underground coal mines in all primary and secondary escapeways and strategic areas as specified in the MSHA Program Policy Letters (PPLs) (MSHA 2006).

POST-ACCIDENT BREATHABLE AIR

The disasters from 2006 demonstrated several shortcomings in breathable air supply technologies, highlighting the fact that few advancements of the technology occurred for more than 30 years while other sectors (e.g., aerospace, maritime workers, and fire-fighting applications) had implemented several additional generations of technology during that same time. Therefore, this technology area was specifically identified in the MINER Act as a major area of research. Unlike in other sectors, mine workers must be under apparatus for a significant period of time and transition between devices while in an atmosphere that is immediately dangerous to life or health (IDLH). The key technology challenges related to SCSRs were (1) device efficiency (e.g., duration, temperature of breathable air, size); (2) risk of exposure to harmful toxics when transitioning to a new device and (3) a breathable air delivery method (i.e., mouthpiece) that made verbal communication unsafe in an IDLH atmosphere. The specific requirement of the MINER Act as included in a mine's ERP is "introducing new self-rescuer technology, such as units with interchangeable air or oxygen cylinders not requiring doffing to replenish airflow."

NIOSH's approach to the problem

In 2013, NIOSH issued changes in certification requirements (42 CFR 84-O) to ensure that the approval criteria for SCSRs more accurately reflects human breathing effort during an escape scenario. While these changes helped to ensure that SCSRs would better support the physiological needs of an escaping mine worker, they also further exacerbated the need for better device efficiency to achieve a small-size SCSR that could be carried on the person at all times. Therefore, in anticipation of the new certification requirements, NIOSH also initiated a comprehensive research and development effort in 2007. NIOSH's research and development effort addresses all three of the SCSR technology challenges — device efficiency, potential for exposure to an IDLH atmosphere while transitioning between devices (dockability), and communication ability. To improve SCSR device efficiency, NIOSH has funded technology advancements for key areas within the apparatus including carbon dioxide scrubber design using lithium hydroxide sheets, very high-pressure oxygen cylinders as part of a compact oxygen delivery system, breathing loop geometry to reduce breathing resistance, incorporating heat exchanging material to lower breathing temperature, and investigating novel chemical mixtures for producing breathable air/absorbing carbon dioxide. To reduce the risk of exposure to an IDLH environment while transitioning between devices or while communicating with other escaping mine workers, NIOSH has developed facepieces (hoods and masks) to eliminate the reliance on a mouthpiece and has also developed components that will allow all SCSRs to be dockable with each other or to an open-circuit breathing apparatus (SCBA). Thus, at no time would the mine worker's lungs be exposed to the IDLH atmosphere once the SCSR is initially donned. While incorporating these improvements and features, human factors considerations and durability are taken into account to make the SCSR comfortably wearable by the miner with minimal interference with normal work when underground. All of these SCSR component improvements are in a prototype stage and will next be demonstrated in a realistic mine escape scenario through usability studies. These next-generation dockable SCSR devices with facepieces for communication ability will be termed closed-circuit mine escape respirators (CCMERs).

In addition to addressing these issues for the SCSR, NIOSH's research and development effort also considers the potential benefits of incorporating additional breathing air supply technologies into the self-escape process. These additional "partner technologies" include an SCBA and compressed air refill stations, where the mine worker will transition from the CCMER to the SCBA using the dockable components. Cryogenics technologies are also being explored as an option to provide breathable air to refuge alternatives with the added benefit of heat and humidity removal, as an alternative to SCBA and compressed air refill systems partnered with the CCMERs, ultimately providing the subsequent CCMER-generation technology to further improve device efficiency.

Current state of the industry

Manufacturers recently developed several SCSRs that meet the requirements of 42 CFR 84-O. Therefore, as operators replace expired SCSRs, the new devices will align more closely with physiologic performance demands of the mine workers. The authors project that, within the next five years, manufacturers will begin producing the CCMER devices, which will not only address the physiologic performance requirements but will also include improved efficiencies to reduce size, weight and the temperature of breathable air and include a facepiece in lieu of only a mouthpiece. In addition, CCMER will have the ability to dock to other CCMER and SCBA devices.

TRAINING

The MINER Act required that a mine's ERP "shall provide a training program for emergency procedures described in the plan which will not diminish the requirements for mandatory health and safety training currently required under section 115."

NIOSH's approach to the problem

One of the key focus areas for training was in donning of SCSRs. Evidence strongly suggested that some of the miners in past disasters died due to improper use of their SCSRs and unfamiliarity with how they operate under actual use. NIOSH published a variety of training materials to help meet the training objectives of the Act (NIOSH 2015a). NIOSH also investigated and continues to pursue a variety of novel training mechanisms including virtual reality and social media.

Current state of the industry

The mining industry has adopted and implemented significant training improvements to meet the requirements of the MINER Act. MSHA has incorporated many of the recommendations by NIOSH and others into its new regulations, including a requirement to physically don the SCSRs during training (Mine Emergency Evacuation Training and Drills 2008).

LOCAL COORDINATION FOR EMERGENCY RESPONSE INCLUDING INCIDENT COMMAND AND CONTROL

The MINER Act required that a mine's ERP "shall set out procedures for coordination and communication between the operator, mine rescue teams, and local emergency response personnel and make provisions for familiarizing local rescue personnel with surface functions that may be required in the course of mine rescue work."

NIOSH's approach to the problem

NIOSH reviewed the communications and interconnectivity issues with personnel from MSHA Mine Emergency Operations to better understand the problems that they face in coordinating efforts between their command center, rescue teams, and remote locations (such as gas monitoring at boreholes during a fire). NIOSH examined and demonstrated possible interconnectivity solutions between the remote location and command center through a mock exercise in rough terrain at tourist mine in Pennsylvania, which was arranged under contract through the Center of Excellence for Remote and Medically Under-served Areas (CERMUSA) (Saint Francis University 2009). The CERMUSA study also identified how incident command is coordinated for first responders through the National Incident Management System (NIMS), not typically used by the mining industry.

Current State of the Industry

MSHA has significantly upgraded its communications to remote location surface units as well as to their rescue teams using many of the techniques that NIOSH assisted with developing and demonstrating as previously discussed (MSHA 2015). With support of NIOSH outreach, many of the mining company-funded and state-funded rescue teams have adopted some of these techniques.

REFUGE ALTERNATIVES

Per the MINER Act, NIOSH "shall provide for the conduct of research, including field tests, concerning the utility, practicality, survivability, and cost of various refuge alternatives in an underground coal mine environment, including commercially-available portable refuge chambers."

NIOSH's approach to the problem

NIOSH conducted considerable refuge alternative (RA) research and testing, developed recommendations, and issued its primary report in December of 2007 (NIOSH 2007b), leading to the initial MSHA refuge alternative requirements in 2008. This report identified many areas where additional research was needed, and NIOSH continued that effort, issuing two additional reports in 2014 (NIOSH 2014) that addressed the critically important issues of purging CO upon opening a shelter, and the temperature rise in mobile RAs from the metabolic heat of the occupants and the heat released by the CO_2 scrubbing system. Updates on this research and information on built-in-place (fixed) refuge alternatives (NIOSH 2015b) were presented at meetings of the NIOSH RA Partnership, consisting of RA manufacturers, mine operators, the UMWA, NIOSH researchers, academics, and MSHA observers in February of 2015 and October 2016, and at a webinar in June of 2016. NIOSH has also published several training documents related to the use of refuge alternatives (NIOSH 2009; 2015c; 2015d). NIOSH research on refuge alternatives is ongoing.

Current state of the industry

In December of 2008, MSHA published the final refuge alternatives regulation which contained specific guidelines and drew on parts of the 2007 NIOSH report. The mining industry has installed refuge chambers in all operating coal mines in compliance with the regulation, although the portable RA structures in use (as opposed to built-in-place units, which represent only 3 percent of the RAs in use as of late 2015) were approved as "grandfathered" units. The regulation provided for the use of refuge alternatives that were approved by the states or included in ERPs and in use before March 2, 2009, to be "permitted until Dec. 31, 2018, or until replaced, whichever comes first" (Refuge Alternatives 2008). The NIOSH RA Partnership is providing input to MSHA on regulations and approval processes applicable beyond that date.

MINE SEALS

The MINER Act specified that "the Secretary of Labor shall finalize mandatory health and safety standards relating to the sealing of abandoned areas in underground coal mines. Such health and safety standards shall provide for an increase in the 20 psi standard currently set forth in section 75.335(a)(2) of title 30, Code of Federal Regulations."

NIOSH's approach to the problem

NIOSH had conducted extensive research indicating that pressures from explosions can far exceed the 20 psi minimum pressure requirement of the then-current regulations. This landmark research along with extensive collaboration with MSHA and other NIOSH stakeholders served as the primary input to the revised mining regulations (NIOSH 2007c).

Current state of the industry

The U.S. mining industry has implemented stronger seals in all new U.S. coal mines and rebuilt seals to the new requirements, unless the operator has opted to monitor seals in compliance with the new regulations. The regulations now require that seals be designed to a minimum overpressure of 120 psi unless actively monitored, or unless seals are between the active longwall panel and the previous panel, in which case the minimum overpressure strength is 50 psi (Seal Strengths, Design Applications, and Installation, 2008).

USE OF BELT AIR AND FIRE-RETARDANT BELT

A provision of the MINER Act required the establishment of a technical study panel "which shall provide independent scientific and engineering review and recommendations with respect to the utilization of belt air and the composition and fire retardant properties of belt materials in underground coal mining."

NIOSH's approach to the problem

NIOSH provided the panel with extensive information on the use of belt air for ventilation and the composition of fire-retardant material. The panel reported on many issues, including how recent technological advances could be applied to atmospheric monitoring systems, point-type heat sensors, current state of fire-resistant vs. fireproof belt materials and belt fire suppression systems to improve miner safety (Technical Study Panel 2007). The panel's report drew heavily on NIOSH research, including the recommendation of belt conveyor materials that meet the flame resistance requirements specified in the NIOSH/MSHA-developed belt evaluation laboratory test (BELT) and other test standards. NIOSH also provided key input on fire smoke detection technology, belt fire characteristics and statistics, and related training. Additionally, NIOSH completed research on ventilation related topics as recommended by the panel.

Current state of the industry

As a result of the panel recommendations, the regulations concerning the use of belt air and belt material have been extensively rewritten. These changes are reflected in the current versions of 30 CFR 75.1103-1 through 30 CFR 75.1103-10. All mines are now required to use approved fire-retardant belts that have been subject to large-scale combustion tests that were not required prior to the MINER Act.

CONTINUING IMPROVEMENT BEYOND MANDATED TECHNOLOGIES

The initial technologies that NIOSH and the industry needed to focus on were prescribed by the MINER Act. However, the MINER Act also required continuing development, improvement, commercialization and utilization of safety and health technologies. The Act accomplished this by requiring that emergency response plans be updated every six months and approved by MSHA to afford miners a level of safety protection consistent with the existing standards, to reflect the most recent credible scientific research and make use of current commercially available technology, to account for the specific physical characteristics of the mine, and to reflect the improvements in mine safety gained from experience and other worker safety and health laws.

The MINER Act also charged NIOSH with responsibility for research, development and testing of new technologies and equipment designed to enhance mine safety and health and provided additional authority to fulfill this purpose through a contracts and grants program. To meet this responsibility, for new technologies that are not currently mandated through Congress or a similar source, the NIOSH mining technology program takes a pro-active approach that solicits input from academic researchers, technology innovators and equipment manufacturers. NIOSH, with input from stakeholders (including operators and labor), sets research priorities on an annual basis. Using these priorities as a reference, technology solutions are solicited annually through a broad agency announcement (BAA). The BAA process allows for awards in any safety and technology area, but identifies focus areas that describe some of the most current safety and health issues as guidance to technology innovators interested in responding to the announcement.

There are also efforts that identify possible technology solutions through means other than the BAA. One of those means is to solicit ideas and support from other government agencies by establishing inter-agency working groups to share technology and technological research and development that could be used to enhance mine safety and accident response. To this end, the NIOSH mining program has executed inter-agency agreements (IAAs) with 12 different federal agencies. Requests for proposals (RFPs) have also been issued on select research topics.

NIOSH has awarded over 150 major contracts since the MINER Act through the BAA, IAA and RFP contracting process. These contracts address mine worker health and safety challenges that fall into one of seven major categories (Fig. 1).

In addition to the work already described, many of these contracts have contributed directly to the advancement of technology-based products. Although some of these products have yet to achieve widespread commercial success, they have all contributed to the foundation for continuing research and improvement. Examples of these contributions are included in Table 1.

An additional part of the continuing improvement efforts are "capacity-building" BAAs, which are issued separately from the technology BAAs. The resulting contract awards are part of the NIOSH response to the MINER Act requirement to increase the nation's skilled workforce to address critical health and safety problems in U.S. mines. NIOSH uses capacity-building contracts to help to produce graduates with advanced degrees in mining and minerals engineering, and to help develop tenure-track faculty performing research in safety and health related areas. As of 2016, OMSHR had provided capacity-building funding in ventilation (nine different universities, 11 different faculty members) and ground control engineering (eight different universities, 10 different faculty members), and had supported a total of 134 graduate students, 65 current students, and 64 MS or PhD successfully graduating degree holders since the program's inception in 2009 (NIOSH 2016a).

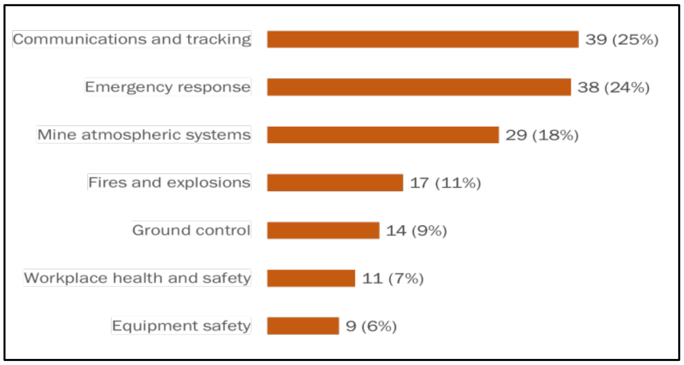

Figure 1. Major contract awards by safety and health category.

Table 1. Technology product advancement by safety and health category.

Safety and health category	Technology product advancement description
Communications And tracking	✓ Mesh-based primary communications system. ✓ Enhanced leaky feeder system for post-accident communications. ✓ Node-based tracking system integrated with the communications system. ✓ Medium frequency communications system easily adaptable for post-disaster communications. ✓ Standalone through-the-earth communications systems.
Emergency response: Self-escape And rescue	✓ Snake robot to be lowered through a borehole for post-disaster exploration of otherwise inaccessible areas. ✓ Scout robot for mine exploration ahead of rescue teams as assistance during the rescue process. ✓ Mantrip outfitted as a mine escape vehicle capable of being operated in zero-visibility post-disaster. ✓ Design and fabrication of key time-critical drilling components—now permanently housed with MSHA for rapid deployment—based on a comprehensive review of large-diameter drill technology for mine rescue used at Que Creek and in Chile. ✓ Oxygen dosing system for extending the utilization life of self-contained self-rescue breathing air supplies, based on the oxygen content of the mine atmosphere, and with potential applicability primarily in metal/nonmetal mines
Equipment safety	✓ Identification of lithium-ion battery safety classifications and alternative lithium-ion chemistries. ✓ An assessment of large-format batteries used underground.
Fires And explosions	✓ In-mine inertization system for producing nitrogen to inert the area behind mine seals. ✓ Application of a fire blocking gel for control of mine fires and refuge alternatives. ✓ Seal strengthening method using polyuria. ✓ Additive to produce anticaking rock dust for improved inertization of float coal dust and explosion prevention. ✓ On-demand trickle dust rock dust application based on float dust generation.
Ground control	✓ Significant improvements in ground control modeling. ✓ Ground movement assessment technologies.
Mine Atmospheric systems	✓ Intrinsically safe mine atmospheric monitoring systems (AMS) and components for utilization in active mine sections, sealed areas, and for post-disaster evaluations. ✓ Wearable low-cost sensors for various key mine gases. ✓ Simulation capabilities of the impact of mine fires on ventilation systems.
Workplace Health and Safety	✓ Improved LED lighting systems for helmets and machines. ✓ Improved training methodologies. ✓ Improvements in the utilization of injury surveillance data to guide hazard identification. ✓ Safety culture assessment methodologies.

THE NIOSH MINING TECHNOLOGY PROGRAM: THE NEXT 10 YEARS

As we move beyond the first decade of the MINER Act, it is important that we celebrate the successes that were achieved through cooperative efforts among Congress, NIOSH, MSHA, mine operators, labor and equipment manufacturers. And, it is equally important to consider the lessons learned in preparation for continued success in the second decade. However, it is also essential to recognize that future success may require a very different approach.

The mining technology program refers to the extramural part of the NIOSH Mining Program, where the majority of efforts are developed and executed by technology innovators from universities, manufacturers, and other entities outside of NIOSH. The program provides funding through contracts, grants, and cooperative agreements. While the technological challenges were significant and more work, currently ongoing, is required to fully meet the MINER Act intent (primarily in systems survivability, breathing air supplies and refuge alternatives); the progress has been outstanding.

In the first decade after the Act, the NIOSH mining technology program efforts were largely directed at research and development (R&D) to achieve congressionally mandated capabilities. In the next decade, NIOSH faces a different R&D challenge in which the technological capabilities to be developed and introduced into mines are no longer mandated by Congress, but must instead be determined by NIOSH and its stakeholders. This will involve a rather complex consideration of the relative costs and benefits of technologies, along with the timeliness and feasibility of introducing the technologies into the U.S. mining regulatory and approval structure. The National Occupational Research Agenda (NORA) program, which solicits input from a broad range of stakeholders, will provide valuable input to this process. This involvement will be an integral part of the NORA program as it is renewed for the third decade, which is coincident with the second decade of the MINER Act (NIOSH 2016b).

The NIOSH mining technology program has been built around cooperation between NIOSH, MSHA, mine operators, labor and equipment manufacturers. In continuing collaboration with these stakeholders, it is important that the business case for safety and health technologies be considered as early as possible in the development cycle. NIOSH and its stakeholders need to find ways to identify and foster partnerships and co-development efforts that can maintain and improve safety while also maintaining the competitiveness of the U.S. mines in the global market.

NIOSH needs to consider not only the lessons learned in the first decade, but also the best methods for managing such a technology R&D program. In most, if not all organizations, there is a "phased view" of R&D, often referred to as a product development life-cycle. One model for the management of technology development programs is maintained by the U.S. Department of Defense (DOD). This process is widely recognized due to the large expenditures by DOD for technology development, and it has been tailored by many technology development companies and government agencies for their particular purposes.

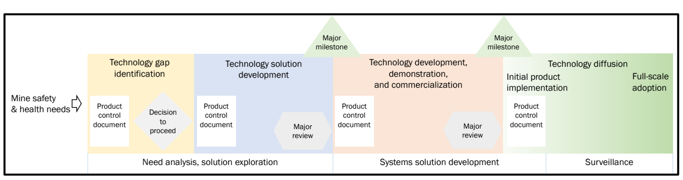

Figure 2. Simplified illustration of how a product development life cycle can be viewed as four phases, including decision points, major milestone reviews, and requirements documents (after DOD 2015).

In the next decade, NIOSH and its stakeholders should consider an approach that better captures the attributes of a complete product development life-cycle management process, as illustrated in Fig. 2. Such an approach will provide a better understanding and improved transparency of the desired capabilities, the challenges in achieving them, the current status of the progress related to the technology objectives and the concrete safety and health benefit of achieving the capabilities. However, the NIOSH role may involve coordination, documentation, tracking, or oversight and resource support of certain parts of the life cycle — since unlike DOD, NIOSH is not an end user but a partner in technology development. For NIOSH, decision points and milestones are collaborative decisions among stakeholders including manufacturers, mine operators, labor and government regulators. The level of involvement of NIOSH in any part of the life cycle will vary substantially depending on the technology and stakeholder interest. Therefore, the universally consistent role for the NIOSH mining technology program amidst such developments is the tracking and assessment of these technologies.

Of particular need for process improvement is the late stages of the development cycle, which is the transition from a mine-worthy prototype of the technology to full adoption and implementation by mine operators. NIOSH experience suggests that the small size and specialized design requirements of the underground coal mine market may be an impediment to the development of new technologies. There are also far more subtle issues that delay or prevent adoption of safety and health technologies. NIOSH and its stakeholders need to grow even further in our understanding of this gap and champion an improved transparency of the adoption challenges that the mining industry faces, so that NIOSH can make timely and more fully informed selective investments to advance future safety and health technologies, in accordance with the intent of the Act.

WHAT DOES THE FUTURE HOLD FOR "MINER ACT TECHNOLOGY"?

For the MINER Act to meet the long-term objective of establishing and maintaining a high level of safety and health using conventional methods and/or state-of-the-art technologies, there must be an ongoing, efficient way to implement such technologies. In mining or any industry, companies are more likely to invest in S&H technologies that provide a substantial safety and health benefit and/or productivity improvement. In addition to the cost/benefit threshold, mining technologies are faced with an additional test that is unique to the industry. The MINER Act, and preceding Mine Acts, require that changes to standards and practices (as needed for introduction of new technologies) must "afford miners a level of safety protection at least consistent with the existing standards."

In the first decade, with the clear requirement by Congress via the MINER Act for the introduction of specific technologies, it was not necessary to prove that there would be equivalent or improved safety by introducing these technologies into the mines. The Act made it clear that the mines *must* have these systems. During the second decade after the MINER Act, the mining industry and MSHA will again need to demonstrate that changes to its standards and practices will result in a mine system that is at least as safe as that provided by current regulations. The special challenge will be that many technologies will likely result in a shift in how protections are provided to mine workers — e.g., automated versus manual interventions — and there must be more efficient ways to demonstrate the equivalent level of safety protections for the industry to support this shift in the absence of explicit congressional language. A fundamental and significant question that needs to be considered in the next decade is: How can it be demonstrated that there is an economic benefit and an equivalent level of safety and health protection for new technologies designed to prevent or respond to catastrophic events — i.e., incidents that have high impact but rarely occur?

Given these and other challenges, and considering the rapid adoption and evolution of technology in the commercial world outside of underground coal mining, it is easy to understand how the industry could once again migrate toward technology stagnation at least as it relates to catastrophic events. The main goal of the NIOSH mining technology program is to continue the progress toward developing and implementing improvements to the existing systems, and to help introduce new technologies as they are developed to improve safety and health — even in areas not specifically addressed in the Act. Many factors can render technologies that are available to other industries to be unavailable to the mining industry. However, NIOSH Mining, MSHA and the industry all owe it to our nation's miners — and to those who have lost their lives in accidents or disasters — to do whatever we can to ensure that the need does not arise for another MINER Act.

The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

REFERENCES

Damiano N., Homce G., and Jacksha R., 2014. A review of underground coal mine emergency communications and tracking systems in the U.S., Coal Age Magazine, Nov., pp. 34–35.

DOD, 2015. DOD Instruction 5000.02 Operations of the Defense Acquisition System. Washington, DC: Department of Defense.

Mine Emergency Evacuation Training and Drills, 2008. 30 CFR 75.1504. http://www.ecfr.gov/cgi-bin/text-idx?SID=544c9dd4e861f4dfb450bdeecd7020cb&mc=true&node=se30.1.75_11504&rgn=div8.

MINER Act Public Law 109-236. MINE IMPROVEMENT AND NEW EMERGENCY RESPONSE ACT OF 2006. http://arlweb.msha.gov/MinerAct/2006mineract.pdf.

MSHA, 2006. Program Policy Letter No. P06-V-09. Implementation of Section 2 of the Mine Improvement and New Emergency Response Act of 2006, Reissue of P06-V-08. Arlington, VA: U.S. Department of Labor, Mine Safety and Health Administration.

MSHA, 2015. From the Assistant Secretary, April 8 2015, Arlington, VA: U.S. Department of Labor, Mine Safety and Health Administration https://www.msha.gov/news-media/assistant-secretary/2015/04/08/msha-leads-game-changing-advance-mine-rescue, Date Accessed: September 12, 2016.

NIOSH, 2005. Fire response preparedness for underground mines. NIOSH Information Circular IC 9481, U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

NIOSH, 2007a. Basic Tutorial on Wireless Communication and Electronic Tracking: Technology Overview. (updated 2013) Pittsburgh, PA: National Institute for Occupational Safety and Health, http://www.cdc.gov/niosh/mining/content/emergencymanagementandresponse/commtracking/commtrackingtutorial1.html, Date Accessed: March, 2016

NIOSH, 2007b. Research Report of Refuge Alternatives for Underground Coal Mines. Pittsburgh, PA: National Institute for Occupational Safety and Health, http://www.cdc.gov/niosh/mining/UserFiles/works/pdfs/Report_on_Refuge_Alternatives_Research_12-07.pdf Date accessed: March 10, 2016

NIOSH, 2007c. Explosion Pressure Design Criteria for New Seals in U.S. Coal Mines. NIOSH Information Circular IC 9500, U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

NIOSH, 2009. Harry's Hard Choices: Mine Refuge Chamber Training. NIOSH Publication No. 2009-122, Information Circular IC 9511, U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

NIOSH, 2014. Mining Feature: Announcing Two New Sister Publications on Refuge Alternatives. Pittsburgh, PA: http://www.cdc.gov/niosh/mining/features/AnnouncingTwoNewSisterPublicationsonRefugeAlternatives.html Date accessed: March 10, 2016.

NIOSH, 2015a. NIOSH Tools You Can Use webpage. http://www.cdc.gov/niosh/mining/Works/ProductList.html#top

NIOSH, 2015b. Facilitating the Use of Built-in-Place Refuge Alternatives in Mines. DHHS (NIOSH) Report of Investigations 9698, Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

NIOSH, 2015c. NIOSH Mining Topic: Refuge Chambers webpage. http://www.cdc.gov/niosh/mining/topics/RefugeChambers.html

NIOSH, 2015d. NIOSH Mining Refuge Alternative Software and Guidance for Underground Coal Mines Supplemental Information webpage. http://www.cdc.gov/niosh/mining/content/refugealternativemoreinfo.html

NIOSH, 2016a. NIOSH Mining Contracts webpage. http://www.cdc.gov/niosh/mining/researchprogram/contracts/index.html

NIOSH, 2016b. NIOSH NORA Mining Sector Council webpage. http://www.cdc.gov/niosh/nora/councils/mining/default.html

Saint Francis University, 2009. Mobile Adaptable Telecommunications RF/IT Infrastructure Experimental (MATRIX): Augmentative Ground-based Communications. Loretto, PA: Center of Excellence for Remote and Medically Under-served Areas (CERMUSA) NIOSH contract no. 0000HCCB1-58366.

Refuge Alternatives, 2008. 30 CFR 75.1506. http://www.ecfr.gov/cgi-bin/text-idx?SID=544c9dd4e861f4dfb450bdeecd7020cb&mc=true&node=se30.1.75_11506&rgn=div8.

Seal Strengths, Design Applications, and Installation, 2008. 30 CFR 75.335. http://www.ecfr.gov/cgi-bin/text-idx?SID=544c9dd4e861f4dfb450bdeecd7020cb&mc=true&node=se30.1.75_1335&rgn=div8.

Technical Study Panel, 2007. Final Report of the Technical Study Panel on the Utilization of Belt Air and the Composition and Fire Retardant Properties of Belt Materials in Underground Coal Mining, by JM Mutmansky, JF Brune, F Calizaya, TP Mucho, JC Tien, JL Weeks. Washington, DC.

Virginia Tech, 2014. Uniform Methodology for Evaluating Coal Mine Tracking Systems. Blacksburg, VA: Virginia Center for Coal and Energy Research, NIOSH contract no. 2010-N-12081 http://www.cdc.gov/niosh/mining/researchprogram/contracts/contract200-2010-36140.html. Data Accessed: September 14, 2016.